

Distance technologies for patient monitoring

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Medical technology once used exclusively in hospitals and general practices is now available for use in the home. A growing selection of innovative electronic monitoring devices is available, but meaningful communication and decision supports are also needed for both patients and clinicians. Several randomised clinical trials of home distance monitoring of glucose concentrations by computer found improved outcomes in diabetes care. Likewise, trials of home distance monitoring of blood pressure show enhanced efficiency. Failure to improve outcomes of high risk pregnancies through home distance monitoring illustrates the difficulties in certain clinical applications. Overall, electronic monitoring at home promises cost effective health services, more active involvement of patients in their own care, and a new sense of realism in making a diagnosis.

Summary points

Emerging home monitoring technologies can transform episode driven health services into a relationship based continuum of care

A growing array of home monitoring devices is commercially available and becoming increasingly affordable

Distance monitoring has been shown to improve the clinical outcome of diabetes care

Home monitoring of pregnant women illustrates the challenge of improving health and also the need for economic consideration when outcomes are equal

Nocturnal haemodialysis, home sleep analysis, and measurement of self care behaviours are among the innovative applications of electronic monitoring

The anticipated information surge from patients' homes calls for computerised data processing and active decision support

Further randomised clinical trials of distance technologies could produce the scientific evidence regarding safety and efficacy in various areas of care

Electronic monitoring devices for home use

Medical technology is now available for use in the home (box). Numerous studies have explored the clinical application of novel monitoring devices, for example, a whole blood prothrombin time monitor,² a portable sleep monitor,³ an electronic spirometer.^{4,5} Telephone and videoconferencing equipment can be used for the measurement of mobility, sleep patterns, and self care behaviours, such as cooking, washing, and toileting, and can properly identify changes in the functional health status of patients at home.⁶

Selected commercially available monitoring devices

Electronic stethoscope
Electronic blood pressure monitor
Pulse oximeter
Electronic contact skin surface microscope
Glucometer
Electrocardiograph

Distance technologies

With access to home monitoring devices, computers, and communication networks, patients can become more active in their own health care. This review lists available technologies for home distance monitoring, assesses its clinical value, and identifies criteria for its appropriate use. Some of the articles included in this review were already in place as part of the Columbia registry—a systematic collection of trials of information and utilisation management at the University of Missouri's school of medicine.¹

The gamut of home distance monitoring

Home distance monitoring often requires the creative use of not just various measurements or monitoring devices but also communication technologies and organisational support services.

Home distance monitoring promises a new sense of realism in the evaluation of paediatric obstructive sleep apnoea syndrome secondary to adenotonsillar hypertrophy.⁷ Home monitoring was shown to be accurate while sleep deficiency was less at home, and the median environmentally induced arousal index was lower than in the laboratory.

Communication and computerised decision support

Communication tools are needed for patients in their home and also for clinicians receiving information from a multitude of sources (for example, interactive telephone based systems and computer networks). Often store forward techniques (data collected and transported later) work better than live communication. In a group of infants who were either premature, had had apparent life threatening episodes, or had siblings who had died from sudden infant death syndrome, monitors recorded all episodes of apnoea greater than 15 seconds and bradycardia episodes less than 80 beats/min.⁸ Information was transferred at regular intervals, and the recordings could validate parental

reports of apnoea episodes at home and could assist in the evaluation of the patients.

With the increase in data volume, computerised decision support can be useful for processing such material. For example, a web based monitoring service for electrocardiograms has been developed to collect clinical data from patients' homes.⁹ The development of a standard communication protocol for computerised electrocardiography represents a major step forward in reliable data transfer.¹⁰ A decision support programme was developed to screen electrocardiographic data and to generate a summary with reminders and suggestions for actions. Another decision support system was developed for the analysis of home monitoring data and treatment planning in gestational diabetes.¹¹

Patient care policies and procedures

Several studies illustrate how home monitoring can be combined with treatment. Pierratos et al reported on nocturnal haemodialysis over 3 years.¹² Nocturnal haemodialysis, a new modality of renal replacement therapy, entails dialysis for 6 to 7 nights per week during sleep at home. The functions of the dialysis are monitored through a modem at a nocturnal haemodialysis centre. The patient must take special precautions to prevent accidental disconnection during sleep and air embolisation. Twelve patients have completed training and successfully performed nocturnal haemodialysis for up to 34 months.¹² Blood pressure control was achieved with fewer drugs, subjective improvement was significant, and complications were infrequent. Nocturnal haemodialysis seems to present an efficient form of dialysis at low cost.

In Germany the success of a programme to help patients monitor their own coagulation status was helped by the development of a structured training programme by the Association of Self Management of Anticoagulation and a reimbursement system by health insurance companies. Several clinical studies have shown that patients who monitor their own coagulation status remain within the treatment range and tend to have fewer

incidences of bleeding or thromboembolic complications than patients who are tested conventionally.

Controlled trials of home distance monitoring

Randomised controlled clinical trials represent the planned experimental approach of evaluation, and they can provide the most reliable information about the clinical value of home distance monitoring. Fortunately, a growing number of randomised controlled trials in health services research, including evaluations of home distance monitoring, have been reported in recent years.¹³

Better outcomes

Several studies of computerised home distance monitoring in the management of diabetes found improved outcome effects.¹⁴⁻¹⁷ In one study a significant improvement in glycohaemoglobin concentrations was found in a group of 56 diabetic patients sending details of their glucose concentrations through a modem to their physicians compared with a control group entering their glucose concentrations in diaries (8.9 v 9.3; $P < 0.05$).¹⁴ Two other studies also found that glucose monitoring by telemedicine led to significant reductions in glucose concentrations in the modem group (22 patients; 13.2% improvement) compared with the control group (20 patients; 8.9% improvement).^{15, 16} In one of these trials¹⁵ a follow up questionnaire showed that patients in the modem group had developed a better understanding of blood glucose control and an improved motivation for self management. Evaluation of remote access to Diabeto, a computer assisted diet education system, found that it significantly improved dietetic knowledge (8% v 2% improvement; $P < 0.0005$), dietetic habits, and metabolic balance as opposed to no access for 105 patients in a cross-over trial.¹⁷

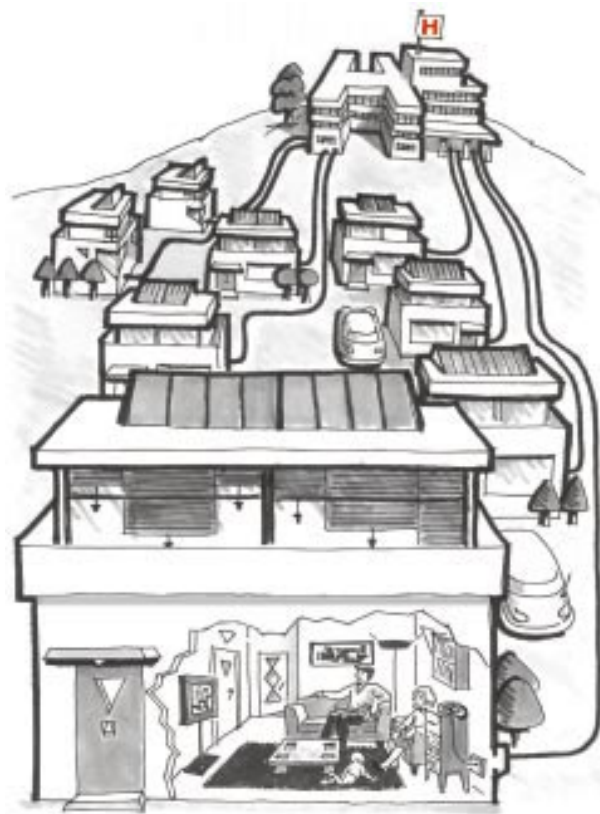
Difficulties in achieving better health

Home monitoring of pregnant women at risk of preterm labour and fetal mortality illustrates the difficulty of researchers in some clinical applications. To achieve appropriate blood glucose control in diabetic women during pregnancy frequent admission to hospital has been recommended, particularly in the third trimester. Numerous randomised controlled clinical trials evaluated the effect of home care on outcome of high risk pregnancies.¹⁸⁻²⁰ Patients in the intervention group were instructed to perform self monitoring at home—for example, for blood glucose concentration, uterine activity, and fetal heart rate. The frequency of pregnancy complications, likelihood of preterm delivery before the 36th week of gestation, problems of blood glucose control, and prenatal death rates were not significantly different between mothers who were monitored at home and those who were admitted to hospital or received visits by nurses during the same period.

Equal care promises cost saving

In a prospective randomised controlled clinical trial at four medical centres 31 patients in the intervention group were asked to measure their blood pressure twice weekly and to send a record of their blood pressure readings, changes in antihypertensive drugs, and any possible side effects by post every 4 weeks. The recorded data were transferred to a clinical computer, and reports were generated for each patient's physician. Patients who did not submit blood pressure readings on time were contacted by telephone. The 31 patients in the intervention group had 1.5 visits to their physician during the study year whereas the 31 patients in the control group (usual care) had 2.7 visits per year. According to one study doctors' prescribing decisions may also be influenced by evidence from self measurement of blood pressure.²¹

Controlled clinical trials are emerging in other application areas. In 1998, Fry et al evaluated the use of 77 unattended full



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polysomnography in the home by the DigiTrace Home Sleep System.²² Their prospective crossover study concluded that by using the system, unattended full polysomnography can be performed in the home with reliable and high quality recordings, and that significant reductions in costs can be achieved owing to the elimination of overnight staff and facility expenses.

Conclusions

Distance monitoring should extend beyond data collection and generate feedback, prompt preventive care, and support patient education. Future telehealth applications are likely to combine initial screening, measurement devices, patient education, decision support, appropriate telephone and video contacts, home visits, emergency support services, and physician access.

Available studies are unspecific about the impact of increased technical sophistication on patient access to quality health care. The role of computer literacy and the need for training clinicians particularly need clarification in future studies. Evidence based healthcare policies could facilitate the development of home care technologies and also accelerate the introduction of these technologies in patient care. Observations from randomised controlled clinical trials show that millions of physician visits could be avoided annually. As expectations are growing the European Commission wants more research on the application of distance care technologies.

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- 1 Balas EA, Stockham MG, Mitchell JA, Austin SM, West DA, Ewigman BG. The Columbia registry of information and utilization management trials. *J Am Med Inf Assoc* 1995;2:307-15.
- 2 Massicotte P, Marzinotto V, Vegh P, Adams M, Andrew M. Home monitoring of warfarin therapy in children with a whole blood prothrombin time monitor. *J Pediatr* 1995;127:389-94.
- 3 Mykityn U, Sajkov D, Neill AM, McEvoy RD. Portable computerized polysomnography in attended and unattended settings. *Chest* 1999;115:114-22.

- 4 Lindgren BR, Finkelstein SM, Prasad B, Dutta P, Killoren T, Scherber J, et al. Determination of reliability and validity in home monitoring data of pulmonary function tests following lung transplantation. *Res Nurs Health* 1997;20:539-50.
- 5 Finkelstein SM, Snyder C, Edinstibbe C, Chlan L, Prasad B, Dutta P, et al. Monitoring progress after lung transplantation from home-patient adherence. *J Med Eng Technol* 1996;20:203-10.
- 6 Nakamura K, Takano T, Akao C. The effectiveness of videophones in home healthcare for the elderly. *Med Care* 1999;37:117-25.
- 7 Jacob SV, Morielli A, Mograss MA, Ducharme FM, Schloss MD, Brouillette RT. Home testing for pediatric obstructive sleep apnea syndrome secondary to adenotonsillar hypertrophy. *Pediatr Pulmonol* 1995;20:241-52.
- 8 Gibson E, Spinner S, Cullen JA, Wrobel HA, Spitzer AR. Documented home apnea monitoring—effect on compliance, duration of monitoring, and validation of alarm reporting. *Clin Pediatr* 1996;35:505-13.
- 9 Magrabi F, Lovel NH, Celler BG. A web-based approach for electrocardiogram monitoring in the home. *Int J Med Inf* 1999;54:145-53.
- 10 Fayn J, Conti L, Fareh S, Maison-Blanche P, Nony P, Rubel P. Interactive and dynamic ECG analysis. Is it just an IDEA or a clinically relevant approach? *J Electrocardiol* 1996;29:21-5S.
- 11 Hernando ME, Gomes EJ, Delpozo F, Corcoy R. Diabet—A qualitative model-based advisory system for therapy planning in gestational diabetes. *Med Inf* 1996;21:359-74.
- 12 Pierratos A, Ouwendyk M, Francoeur R, Vas S, Raj DSC, Ecclestone AM, et al. Nocturnal hemodialysis—three year experience. *J Am Soc Nephrol* 1998;9:859-68.
- 13 Balas EA, Jaffrey F, Kuperman GJ, Austin Boren S, Brown GD, Pincioli F, et al. Electronic communication with patients: evaluation of distance medicine technologies. *JAMA* 1997;278:152-9.
- 14 Rosenfalck AM, Bendtsen I. The Diva system, a computerized diary, used in young type 1 diabetic patients. *Diabete Metabolisme* 1993;19:25-9.
- 15 Ahning KK, Joyce C, Ahning JPK, Farid NR. Telephone modem access improves diabetes control in those with insulin-requiring diabetes. *Diabetes Care* 1992;15:971-5.
- 16 Billiard A, Rohmer V, Roques M, Joseph MG, Suraniti S, Giraud P, et al. Telematic transmission of computerized blood glucose profiles for IDDM patients. *Diabetes Care* 1991;14:130-4.
- 17 Turin MF, Beddok RH, Clottes J, Martini PF, Abadie RG, Buisson JC, et al. Telematic expert system Diabeto: new tool for diet self-monitoring for diabetic patients. *Diabetes Care* 1992;15:204-12.
- 18 Brown HL, Britton KA, Brizendine EJ, Hiatt AK, Ingram D, Turnquest MA, et al. A randomized comparison of home uterine activity monitoring in the outpatient management of women treated for preterm labor. *Am J Obstet Gynecol* 1999;180:798-803.
- 19 Moninckx WM, Zondervan HA, Birnie E, Ris M, Bossuyt PMM. High-risk pregnancy monitored antenatally at home. *Eur J Obstet Gynecol Reprod Biol* 1997;75:147-53.
- 20 Dyson DC, Danbe KH, Bamber JA, Crites YM, Field DR, Maier JA, et al. Monitoring women at risk for preterm labor. *N Engl J Med* 1998;338:15-9.
- 21 Bailey B, Carney SL, Gillies AAH, Smith AJ. Antihypertensive drug treatment: a comparison of usual care with self blood pressure measurement. *J Human Hypertens* 1999;13:147-50.
- 22 Fry JM, Diphillipo MA, Curran K, Goldberg R, Baran AS. Full polysomnography in the home. *Sleep* 1998;21:635-42.